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A BRIEF ACCOUNT OF THE PROGRESS OF THE ART OF NAVIGATION.

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Navigation is defined by one of the old writers upon this subject to be "the art of conducting a vessel from one port to another in the safest, speediest and most accurate manner, as wind and tide shall serve." This definition is somewhat open to the objection that it brings in the practice of the kindred art of seamanship, with which indeed the practice of navigation is most closely allied. The modern lexicographer defines it as "the art of conducting a vessel from one port to another." Inasmuch as this definition seems to be open to the same objection as the earlier one, I would suggest the following, as defining more clearly the part which navigation properly takes in passing by sea from port to port. "Navigation is the art of determining the position of a vessel upon the ocean at any given time, and obtaining the direction to be pursued from such position to reach any given point."

With the purpose of recounting briefly the various steps in the progress of this art, (from the days when creeping timidly along the coast, the navigators of the past rarely ventured out of sight of land, to the present time when no ocean remains untraversed by the keel of the adventurous mariner, save the waters of the so called Palæocrystic sea, the barriers of which let us hope the genius and daring of the Ameri-

can navigator will yet triumphantly surmount,) I propose to consider the subjects of

First, the CHART;
Second, the COMPASS;
Third, other INSTRUMENTS;
Fourth, the RECKONING.

THE CHART.

The first map of which we have any record was constructed by Anaximander of Miletus, about 610 B. C.; in the state of geographical knowledge existing at that date, this map could have been but rude and imperfect, yet it served its purpose until improved by Eratosthenes, three and a half centuries later. On this map were placed parallels and meridians, not as we place them, at certain fixed intervals, but simply through places whose relative position had been as well determined as possible at that time. There was, therefore, no prime meridian, and the differences of longitude only were given, and (naturally) in the great majority of cases incorrectly. Strabo, writing about the beginning of the Christian era, in reviewing the work of Eratosthenes, seems to have no fault to find with the methods upon which the maps of the latter were constructed; but he confines himself to the correction of the positions assigned to several well known points. In this connection he makes the following assertion; "if the extent of the Atlantic ocean were not an obstacle, we might pass by sea from Iberia to India," which is remarkable as antedating the ideas of Columbus more than fourteen hundred years. Eratosthenes admitted the rotundity of the earth, but made his chart as if it were a plane, asserting that beyond the then known regions the world was uninhabitable. Later (A. D. 150) Ptolemy constructed a map in a more elaborate manner, placing parallels and meridians at equal intervals of five or ten degrees, and causing the meridians to converge in their approach to the regions remote from the equator; there seems to have been no fixed method by which this was done; it shows however, that some dim ideas of the correct principles of cartography were prevalent, even at that early day. For Ptolemy says, "that the degrees of longitude should bear in some measure that proportion to the degrees of latitude, which the magnitude of the respective parallels bears to a great circle of the sphere." These maps sufficed for the use of the navigator, so long as his voyages were confined to coasting; but were of but little use to him after the invention of the Mariner's Compass enabled him to pursue his way across the water remote from land; accordingly soon after the begin-

ning of the impetus given to the progress of maritime discovery, by the aid of that useful instrument, we find that the sea chart came into use.

This chart was the projection of a spherical zone upon a cylinder whose axis was parallel to the axis of the earth, and whose elements intersected the sphere in the middle latitude of the zone under consideration. Upon this chart the parallels and meridians were at right angles: the length of a degree of latitude was assumed to be the same in all latitudes, and was taken on the chart, as sixty minutes of five thousand feet each: the length of a degree of longitude was computed from the formula $L' = L \times \cos$ middle latitude, thus carrying out Ptolemy's principle before referred to. The middle parallel was thus developed in its true length in minutes, but all the others were inaccurate, and the true relation of the parallels and meridians being shown only at the middle latitude, the courses laid down upon the chart were very inaccurate.

The introduction of this chart is ascribed to Prince Henry the Navigator, (A. D. 1400), to whose patronage the navigators of that age were greatly indebted, and to whom Portugal owed the leading position which she then took among the maritime nations. It is evident that this chart must have been, (except for a few degrees on either side of the equator) in the highest degree inaccurate, and but slightly to be depended upon, as being only better than nothing. It was not until one hundred and fifty years later that any marked improvement was made. Yet, during this century and a half, the progress of maritime discovery had been most great: the new world had been brought to light by Columbus; the Cape of Good Hope had been doubled by Vasco de Gama; the earth had been circumnavigated to the westward by Magellan; and the adventurous navigators of every nation had pushed their vessels far beyond the expectations of the most sanguine, thus enlarging the commerce of their respective countries, and preparing a favorable reception for the improvement in the chart introduced by GERARD MERCATOR in 1556. Mercator's original chart, though a most decided advance, was yet full of grave errors; inasmuch as his table of meridional parts was very far from accurate, and consequently his degrees of latitude were not properly expanded.

Although so especially designed for the use of navigators, Mercator's improvement met with great opposition among the very class who were to receive most benefit from it. Some saying, "that by augmentation of the degrees of latitude toward the poles, it is much

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more fit to behold for such as study in cosmography, by reading authors upon land, than to be used in navigation at sea."

Some forty years later, just at the close of the sixteenth century, EDWARD WRIGHT of Caius College, Cambridge, published a work entitled, "Certain errors in Navigation detected and corrected." In the preface to this work he says, "By occasion of the first map of Mercator, I first thought of correcting so many errors, by increasing the distance of the parallels from the equinoctial towards the poles, in such sort, that at every point of latitude in the chart, a small part of the meridian might have the same proportion almost to the like part of the parallel, that it hath in the globe. But the way how this should be done, I learned neither of Mercator nor of any man else." It would seem to be then, an indubitable fact that to Wright is due the credit of constructing a chart after the proper method. In the body of his work he shows that "the length of a minute on the proper meridian must be to the length of a minute on the enlarged meridian as the radius to the secant of the latitude." Upon this theory he constructed his table of meridional parts, supposing the earth to be a sphere. At a later day, when it was determined that the figure of the earth was that of an oblate spheroid, new tables were constructed in consonance with that fact, and these are the ones now in use for the construction of the ordinary sea chart. Other methods of developing the surface of the spheroid upon a plane have been used, each of which has its particular advantages; but for a chart which is to comprise a large extent of the earth's surface, nothing has been devised superior to WRIGHT'S; its disadvantage of the distortion of the surface in high latitudes being far outweighed by its chief merit that the loxodromic curve is represented upon it by a straight line. For surveying purposes, and for a comparatively small area, the ordinary polyconic of the U. S. Coast survey is unquestionably the best; but for large areas and for the general use of the Navigator, WRIGHT'S must be conceded the precedence.

THE MARINER'S COMPASS.

It is entirely unknown to whom is to be attributed the invention of this instrument, so indispensable to the mariner and without which it hardly seems possible that mankind could have reached their present state of civilization. Various have been the speculations upon the matter, with equally various results. The attractive power of the loadstone or magnet was well known centuries before the Christian era: but when the knowledge of its directive power was attained is entirely uncertain

The Chinese claim to have been acquainted with it twenty-five hundred years B. C., and to have used the compass on land since that date: no mention is made in their chronicles of its application to purposes of navigation, until about four hundred years after the birth of Christ; it being stated that at that date "ships were directed to the south by the needle." It is perhaps doubtful if these claims can be substantiated, and we must look to a later day for more authentic information. A writer of the year 1242 states that "the captains who navigate the Syrian seas use a needle to point out the North and South when the stars are obscured;" this was accomplished by placing a needle, immediately after being touched with the loadstone, upon a float of wood in a basin of water.

A manuscript of a date later by a quarter of a century (1269), gives an accurate account of a compass, with an alidade attachment for obtaining the bearing of any heavenly body: in this instrument the needle was not suspended freely, but was inserted in a vertical axis, so that its motion must have been very sluggish indeed. The author of this manuscript was also cognizant of the variation of the Compass, for he says; "Take notice that the magnet, as well as the needle which has been touched by it, does not point exactly to the poles, but that part which looks toward the North declines a little toward the East; the exact quantity of this declination, I have found to be five degrees." If the date assigned to this manuscript be not incorrect, it would seem strange that all knowledge of such an important item as the variation should have been entirely lost two centuries later; for the discovery of the variation is generally ascribed to COLUMBUS, who noticed it in his first trans-atlantic voyage in 1492; it was again discovered independently by SEBASTIAN CABOT in 1497; if we admit the authenticity of the above mentioned manuscript, these were only re-discoveries of that which had been known two hundred years before.

It is probably true that the land compass was known to Europeans at the beginning of the 14th century, but it was not, so far as can be ascertained, applied to nautical uses before that time. In 1362 FLAVIO DE AMALFI made what was probably the first step toward this application; he invented the attachment of the compass card or fly to the needle; and hence he is generally considered as entitled to the honor of being the inventor of the *Mariner's* compass. His compass card was however divided into but eight points; the present sub-division into thirty-two points being of more modern origin.

The dip of the needle was discovered by Robert Norman, an Englishman, in 1576. About 1600, the first extended series of observations upon the variation was undertaken, by direction of Prince Maurice of Nassau, Lord High Admiral of the United Provinces; he ordered all seamen under his jurisdiction to be particularly careful to observe the variation, and on their return from their voyages, to report the results obtained to the Admiralty, in order that they might be collated, compared and published for the benefit of all mariners. As late as 1622, the change of the variation at any place was entirely unsuspected, it being supposed to be a constant quantity; but in that year Gunter found that since the latest observations of Norman a change of five degrees had taken place; this discovery was not then made public, but the observations were recorded for future reference. Thirteen years afterward (in 1635), Gunter's successor renewed the observations and found the change still going on; the results obtained by both observers were then published to the world. Various theories have from time to time been advanced as to the cause of the polarity of the needle and of the annual change of the variation, to enter into any description of which is foreign to the purpose of this paper; Professor Airy, however, sums up the results in the statement that "we must express our opinion that the general cause of the earth's magnetism still remains one of the mysteries of cosmical physics." As we shall afterwards see, it was for a long time hoped that through the variation of the compass might be solved the difficult problem of the finding of the longitude at sea: but it was found to be an inadequate means to this end, and was finally reluctantly abandoned.

The deviation of the compass on board ship seems to have been noticed by Dampier in 1680, and again a century later (in 1769) by Cook; but it was not until the beginning of the present century that Captain Flinders, R. N. called the particular attention of seamen, "to the influence upon the compass of the ferruginous matters on board ship." The later history of the deviation and of the methods of obtaining it, are so familiar to the members of the Institute that it is unnecessary to do anything more than merely mention the fact of their existence.

The needle, as we have seen, was first floated upon wood in water; the next improvement consisted in suspending it by means of a silken thread; and the method of balancing it upon a fine point was soon after adopted. As first used with the card, the latter was poised upon the point of the spindle, and the needle had an elliptical opening

in its centre to admit of this. The next improvement was in the use of a straight needle; and latterly we have the form which is familiar in the shape of the Admiralty compass, with its four compound needles placed parallel to each other, thirty degrees apart.

The present method of suspending the compass bowl in gimbals was invented about 1608, by the Rev. William Barlow, an Englishman. The great oscillation of the ordinary card when running in a heavy sea with a free wind, caused Ingenhous, an Englishman, to propose (in 1799) the filling of the compass bowl with some sort of liquid.

Various improvements have been made from time to time in the construction of various parts of the instrument, until at the present time the high state of perfection to which the liquid compass, as furnished to the Navy by Ritchie, has been brought, would seem to leave no room for further improvement.

Sir William Thomson has devised a compass which is remarkable for the lightness of its construction and the small size of its needles. A central boss of aluminum is connected by means of silk cords with a ring of the same material which forms the outer circumference of the instrument: four needles about 4 inches long and about the size of ordinary knitting needles, are placed on each side the centre, being secured to the cords; by reason of this the weight of the compass is greatly lessened, and the time of its vibration greatly increased, so that it is remarkably steady in a seaway. While very good results have been obtained from this instrument, it would seem that the delicacy of its construction would be an objection to its common use.

INSTRUMENTS.

The next division of the subject leads us to consider the various instruments that have been used at different periods for the purpose of determining the altitude of a heavenly body. These in the order of time are the astrolabe; the sea ring; the cross (or fore) staff; the nocturlabe; the quadrant of Davis, or, as it was sometimes called, the back staff; the single reflecting quadrant of Coles; and lastly, the double reflecting quadrant of Hadley, upon the optical principle of which are constructed also the sextant and the octant.

A description of the astrolabe, cross staff and nocturlabe was given in a paper which I had the honor to read before the Institute several months ago; figures of them [figs. 1, 2 & 3] are given herewith, which sufficiently explain themselves. The sea ring (fig. 4) was considered to be an improvement upon the astrolabe: as generally made it was of

brass, about nine inches in diameter, an inch wide, and from one-sixteenth to one-eighth of an inch in thickness: it was, like the astrolabe, suspended from the thumb of the observer by means of a swivel ring, and was turned to the sun in such manner as to cause its rays to pass through an aperture in the manner shown in the figure; the spot of light upon the inner surface of the graduated arc indicated the altitude; the method employed in the graduation of the instrument is sufficiently pointed out in the figure. It is obvious that both the ring and astrolabe were open to very serious objections as affording only very inaccurate methods of attaining the object sought. The cross staff was therefore a great improvement; having been introduced about 1550. The next advance was made in the quadrant (fig. 5) invented by Captain JOHN DAVIS, an Englishman, about 1590. The instrument was made of wood: the smaller arc was called the sixty arc, from the fact that it contained that number of degrees; the larger arc was called the thirty arc, for a similar reason. The sixty arc was graduated to degrees from 0° to 60°, from the upper part of the arc towards the lower end; the thirty arc was graduated to five minutes from 0° to 30° in the opposite direction, the sum of the figures at the two central extremities amounting to ninety degrees. In using the instrument, the horizon vane at the extremity of the long radius, and sight vane upon the thirty arc were shipped in place as shown by the figure; the shade vane being placed upon the sixty arc so that its upper edge read to a number of degrees less by fifteen or twenty than the estimated zenith distance. The vanes having been thus placed, the observer, turning his back to the sun and looking through the sight vane, caused the upper edge of the shadow cast by the shade vane to lie upon the upper edge of the slit in the horizon vane, through which the horizon would be visible if the sight vane were placed correctly; if this were not the case, the sight vane was moved up or down the limb as necessary, until the horizon and the shadow were in coincidence. The altitude was obviously the angle at the horizon vane formed by the lines drawn from the other vanes; but as the obtaining of this would involve two subtractions and one addition, the zenith distance was obtained directly by adding the reading shown by the shade vane to that shown by the sight vane. The specimen of this instrument which is exhibited, was once the property of Captain JOHN PAUL JONES. Sometimes a vernier was added to the sight vane making the least count of the instrument thirty seconds. It is evident that this quadrant could not be used for observing altitudes of a body whose rays were

not sufficiently strong to cast a shadow; and in this respect it was inferior to the fore staff. Flamsteed improved it by causing a lens to be placed in the shade vane, throwing a spot of light on the horizon vane.

Elton's improvement upon this instrument consisted in placing a spirit level upon the radius, thus allowing the horizon vane to be dispensed with; it is obvious that this so-called improvement was of but doubtful utility for the purposes of the navigator.

Gunter's quadrant was also made of wood, consisting of a sector of a circle whose angle was ninety degrees; upon its face, as a primitive plane (in addition to the graduated limb) were projected stereographically, the equinoctial, the ecliptic, the tropic and various other circles of the sphere. It was not designed to be any improvement over Davis' instrument for taking altitudes, but was intended chiefly for the graphic solution of various problems in nautical astronomy.

Coles' reflecting quadrant (fig. 6) was also constructed of wood, having a movable arm with vernier attached: at the centre of the instrument was a silvered mirror which reflected the rays of the sun through a hole in the sight vane which was situated upon the prolongation of the radius bar beyond the limb. This instrument does not seem to have been much used. Fig. 7 is an illustration of Newton's quadrant, the first double reflecting instrument.

The greatest improvement, however, was that made by Hadley, in 1742, in his double reflecting quadrant. As originally designed, this quadrant had two horizon glasses, being intended for both fore and back observations. The sextant was designed originally for the measurement of lunar distances, and consequently the back horizon glass was unnecessary. In this form it has come down to us, and is now used, as is so well known, for taking altitudes also, the quadrant, with its distinguishing mark of two horizon glasses, having long since been discarded. Various attempts have been made to improve the sextant by placing upon it a spirit level or an artificial horizon, but none of them have been successful for use afloat. A proposition has also been made to place an artificial horizon on gimbals for use at sea, but this also has met with failure.* Some means of determining the zenith distance of a celestial body, when the horizon is obscured, would be gladly welcomed by the navigator. Laurent's night octant, in which the shade glasses are replaced by a plano-cylindrical lens causing the image of the star to

* A *Sea top* in which the instrument was made to rotate rapidly, with the intention of preserving its perpendicularity, and thus giving a correct artificial horizon, was invented about a hundred years ago.

appear reflected as a band of light, has met with great approval for the purpose for which it is intended. A cruder form of a night instrument, in which the instrument is kept horizontal by means of a spirit level, has been devised, but it has not proved at all satisfactory in use.

OTHER DEVICES.

As early as the middle of the sixteenth century Mercator's invention of the celestial globe furnished the mariner with an easy method for the solution of the various spherical triangles involved in different cases of nautical astronomy. Since that day, many devices having the same end in view, have been produced. I refer here however to but three: the first (which is shown) was devised by a graduate of the Naval Academy: it involves no new principles and (being constructed of wood) is valuable chiefly as an exhibition of industry and skill with the jack-knife. A similar instrument to be constructed of brass, has also been devised by another graduate: these gentlemen have evidently been independent inventors. A third instrument called the *Nautrigon* has been constructed upon precisely the same principles as the other two; these principles are identical with those upon which Mercator based his invention; and he in his turn but made an adaptation of the armillary sphere of Ptolemy, who seems to have been the original inventor of the device which has turned up in the different shapes to which I have referred. These and kindred mechanical devices, however, can never supply the place of that practical and theoretical knowledge of which every student of navigation should endeavor to possess himself.

THE RECKONING.

We come next to a consideration of the various means employed for the purpose of keeping an account of the vessel's progress and of determining her position. It is not within the scope of this paper to *discuss* the various methods now in use for the determination of the coordinates of the ship's place upon the surface of the earth; but it is my desire briefly to call attention to the difficulties with which the navigator of the past was weighted, and to the gradual overcoming of them in successive years.

History is unable to point out the beginning of the practice of this art, for from the earliest times of which we have any record, passages by sea have been made. So long as the directive power of the magnet remained unknown, the ancient navigators had no means of guiding their vessels over the waters; and were consequently obliged to remain

enar the land, regulating their direction by means of the sun and stars, chiefly however by the latter. In the words of Dryden,

> "Rude as their ships was navigation then,
> No useful compass or meridian known:
> Coasting, they kept the land within their ken,
> And knew no North, but when the pole star shone."

Under such conditions, but little scope was afforded for anything more than guessing as to the position of the vessel: and yet it would seem to be a well authenticated fact that the bold Phœnician mariners, coasted not only throughout the extent of the Mediterranean, but extended their voyages along the western coasts of Europe and Africa; and it is not entirely beyond belief that the Cape of Good Hope was doubled by these adventurers of 600 B. C.

It was not until the adaptation of the magnet in the shape of the Mariner's compass, that there was furnished a means of keeping any sort of reckoning, when out of sight of land. As, under the guidance of the needle, it was found possible to venture into open water, some means of determining his relative position was demanded by the mariner. As the true form of the earth was considered, the motions of the heavenly bodies studied and the path of the sun approximately mapped out, the problem of the determination of the latitude had been solved on shore long before it was desired for use at sea. And the sea astrolabe for the observation of the meridian altitude of the sun or of the altitude of the pole star, was but a modification of the instrument used on shore for the same purpose. And here let us notice the important part which the science of astronomy performs in laying the theories upon which the practice of the art of navigation is founded. Without the profound investigations of those well versed in this most exact of the mixed sciences, the navigator would even now be at a loss to find his way from port to port.

The latitude then has been always easily determined approximately, by the two methods alluded to: the method by the sun was not accurate, by reason of the imperfection of the solar tables as well as by want of precise means of observing the altitude: that by the pole star was still less accurate, for the amount to be added to or subtracted from the observed altitude, on account of the star's position relative to the celestial pole, was determined only by the very rough method of obtaining the compass bearing of the *pointers* of the Great Bear or the *guards* of the Little Bear: a table being constructed, by entering which with this bearing as an argument could be ascertained the cor-

rection to be applied. As voyages were extended into south latitude and new stars discovered about the south pole, the meridian altitude of the star in the foot of the southern cross was taken; it being known that it was thirty degrees from the pole. This method of meridian altitudes is still the chief reliance of the navigator, and the precision of his results is due to the increased accuracy of his means for determining the declination of the body observed, to the greater nicety of his instruments and to the knowledge of the proper corrections to be applied to the observed, to get the true, altitude.

In the middle of the sixteenth century, the reckoning was kept as follows: as soon as possible after leaving port the latitude was determined, the course steered in the meanwhile having been noted; should the course not have been constant the mariner was directed to estimate as nearly as practicable, the mean of all his courses steered; with this course and the difference of latitude, the distance and departure were obtained from a table which showed "for an alteration of one degree in the latitude, how many leagues had been run on each rhumb, and the departure from the meridian" of the point left. Knowing these quantities the place of the ship was plotted upon the chart; as at this time the plane chart was in use, the difference of longitude and departure were considered to be the same. About this time *Mercator* invented the terrestrial globe and by means of a table which showed the length of a degree of longitude on a given parallel of latitude, the departure could be turned into difference of longitude and the ship's place plotted upon the globe; but of course with results far from the truth, as the determination of the departure was itself liable to most grave errors.

With the advent of WRIGHT'S chart, came the application of this principle to the plotting of the position. If the distance were great, the departure was taken as in the middle latitude, it being very evident that it would be incorrect to use either of the extreme parallels for this purpose. At the same time that WRIGHT constructed his chart, he stated that the position of the ship could be found by calculation, but inasmuch as the courses were liable to great error he thought it advisable to make no change. Handson, in 1614, published solutions of what is known to us as Mercator's sailing. The longitude being so uncertain, the usual practice was to run into the latitude of the port sought, and thence sail East or West: hence the term parallel sailing. But inasmuch as there was no change of latitude upon this course, there was no method of finding the change of longitude, be-

cause there were no means of determining the distance sailed, save its estimation by the navigator, the log at this time not having as yet come into use. Although mention of this indispensable instrument is made as early as 1577, yet it seems not to have come into common use for more than thirty years subsequent thereto.* At this time the length of the knot was generally taken at forty two feet, and a thirty seconds glass used, on the theory that the length of a sea mile was but five thousand feet. WRIGHT called attention to the fact that altitudes observed at sea should be corrected for the dip of the horizon, to determine which it was necessary to know the magnitude of the earth, and he seems to have been the first to construct tables of the dip, although he considered his results to be but approximate; and as his conclusions agreed with the generally received length of a nautical mile, his attention was not drawn to the log line. NORWOOD, in 1635, measured an arc of the meridian, and determined the length of a minute of the great circle to be six thousand one hundred and twenty feet; he thereupon proposed to change the length of the knot upon the log line to fifty feet, to correspond to the thirty seconds glass. So wedded to their custom were the mariners of that day, that (instead of making the change recommended by Norwood), they altered the length of the glass to twenty eight seconds, leaving the knot five feet short of its proper length, a practice which obtained until a recent date.

The Traverse Table, so useful to the mariner in his daily work, seems to have been first published about 1625, by ADDISON, an Englishman. NORWOOD was the first to call attention (in 1637), to the application of the Variation to the Compass Course; and he at the same time proposed a method for ascertaining the existence of a current.

The application of the Refraction to the observed altitude was not made until nearly the middle of the seventeenth century: that of the Parallax, at a later date, when the distance of the sun and moon became approximately known.

The problem of the longitude early engaged the attention and study of mathematicians; and observations of lunar eclipses seem to have first suggested themselves. WERNER of Nuremburg (in 1514), was the first person who proposed the method of lunar distances: the method in brief, was to find the longitude of the moon, by her distance from the sun or other star; from the difference between the true longitude as computed from the tables of the moon's motion and her longitude

* The principle involved in the construction of Massey's Patent Log was first enunciated by Phillips, about 1650.

as found by observation, in connection with her hourly motion, could be obtained the difference of longitude between the place of observation, and that for the meridian of which the tables were calculated.

About 1530, GEMMA FRISIUS proposed the method by time keepers now actually in use; but he did not consider this applicable to sea use on account of the liability of the time pieces to rust. In 1581, Coignet proposed a method to be used in parallel sailing, whereby the distance sailed could be determined by means of the difference of time turned into difference of longitude; this being obtained by keeping a twenty four hour sand glass running from noon at the port of departure, and the number of hours that the sand ran out before or after noon, at the place of arrival gave the difference of time sought. Of course this method was very crude, but it was a great advance beyond any other that had ever been proposed, and it could have been used for determining the difference of time between any two places.

At the beginning of the seventeenth century, PHILIP III of Spain offered a reward of one thousand crowns for a correct solution of the problem; and soon afterward the States General of Holland offered a reward of one hundred thousand florins. Notwithstanding the stimulus offered by these rewards, no new theories were proposed, but some improvements were made in the lunar tables, which though not sufficient to gain the prizes, were yet a step in advance of those formerly in use.

About 1650, BOND announced that "having found the true theory of the variation of the compass," he could thereby determine what the variation ought to be in any given longitude; and hence with the obtaining of the variation by any of the usual methods, the longitude would at once be known. As a proof that he had discovered the true theory, he foretold that the variation at London (being then easterly), would in 1657, be zero; and would afterward change to westerly; which prediction proved true. But unfortunately it was found that Bond's hypothesis was not correct, and that no good results could be obtained. Accordingly HALLEY undertook the subject, and after discussing a large number of observations, he formed a theory as to the location of the four magnetic poles, and published (in 1700), a chart with the lines of equal variation upon it, and he hoped that this would greatly assist the mariner in finding his longitude. Some twenty years after, a dip chart was published with the same end in view, but neither of these methods could be successful, as can be readily seen from the various directions of the isogonic and isoclinic lines in reference to the meridians and parallels.

In 1675 the Royal observatory at Greenwich was founded; and FLAMSTEED appointed to its charge as the first Astronomer Royal. He was particularly enjoined "to apply himself with the utmost care and diligence to the rectifying the tables of the motions of the heavens and the places of the fixed stars, in order to find out the so much desired longitude at sea, for perfecting the art of navigation." Flamsteed said "that after two thousand years we find the best tables erring sometimes twelve minutes or more in the moon's apparent place, which would cause an error of half an hour or seven and one half degrees of longitude, by comparing her place in the heavens with that given in the tables."

Eclipses of Jupiter's satellites were also recommended; and in 1693 Cassini published, under the patronage of Louis XIV, tables for facilitating the use of these phenomena; this method, however, has never been found useful at sea.

In 1714, the English parliament constituted a Board of Longitude and offered a reward of twenty thousand pounds sterling for any method by which the longitude could be determined at sea within thirty miles; fifteen thousand pounds sterling, if it could be determined within forty miles, and ten thousand pounds sterling, if the method were sufficiently accurate to obtain it within one degree. In 1716, a reward of one hundred thousand livres was offered by the Duke of Orleans. The stimulus of these magnificent offers, and the improved means of correcting the lunar tables owing to the profound investigations of Newton, urged many to compete for the prize.* In 1755 *Mayer's* tables gave the place of the moon to within one minute; and his widow received three thousand pounds

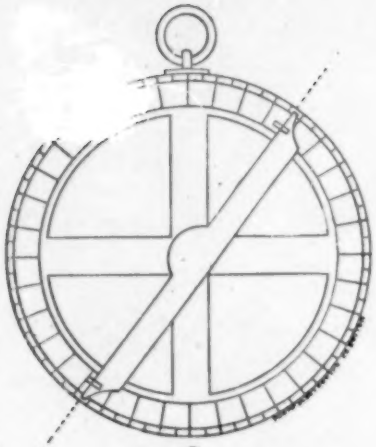
* As showing the necessity which existed for greater accuracy in finding the longitude the following instance is cited. In Commodore Anson's voyage around the world in 1740–44, while beating to the westward around Cape Horn, the squadron was by reckoning (after making, as was supposed, sufficient allowance for an easterly current) in latitude 54° 30′ S., longitude 87° 30′ W. Seeing himself well clear of the cape the Commodore was standing to the Northward with a favoring breeze, when suddenly, about two o'clock in the morning, land was seen directly ahead and but a few miles distant; the squadron was at once hove to until daylight, when it was found that they were off Cape Noir; whose latitude was the same as that in which their reckoning placed them, but whose longitude was 78° 45′ W.; nearly nine degrees (or *three hundred miles*) east of their estimated position! With such difficulties were the navigators of but little more than a century since obliged to contend.

sterling as a reward therefor. These tables were immediately printed; and in 1766 was published the first issue of the British Nautical Almanac containing not only these tables but the directions for using them, and for interpolating, by means of proportional logarithms; these were devised by MASKELYNE, who was then Astronomer Royal.

In a voyage to St. Helena, Maskelyne tested these tables and found his longitude by observation to be within a degree of the truth; while that by the dead reckoning was many degrees out; in a subsequent voyage to Barbadoes, he was by his observations within thirty minutes of his true position on making the land, and on his return was but sixteen minutes out in making the Isle of Wight. On this last voyage he also invented the method of ascertaining the index error of the quadrant by measuring the sun's diameter on and off the arc. These results led many others to endeavor to improve the methods for the reduction of the apparent to the true distance and the finding of lunar distances has remained, until a comparatively recent period, the chief reliance of the navigator. Other lunar methods have been proposed; among which may be mentioned that by the meridian altitude of the moon; but, inasmuch as this requires an exact measurement of the altitude and a correct knowledge of the latitude, it can hardly be said to be of any use at sea. While the method by means of lunar distances is still taught, yet its chief use is that of giving us a check upon the chronometer; which brings us to consider the modern method. As already noticed, Gemma Frisius gave us the theory,—but it remained for later generations to construct a timepiece which should fulfill the conditions required. In 1662, a pendulum clock was tried at sea, the clock being weighted and suspended near the centre of motion of the ship; the attempt was fairly successful. About this time the balance spring was applied to the clock, rendering a pendulum unnecessary, but no more trials of this method seem to have been made during the succeeding half century. The reward offered by the Board of Longitude, however, inspired the watchmakers to attempts at such improvements in their instruments as might gain the coveted prize. In 1736, HARRISON made the first trial of his chronometer with a very fair measure of success; for this he received a portion of the reward from the Board, with an intimation of their desire for a further prosecution of his design.

Three years later, he produced a second, which gave better results than its predecessor; ten years later, a third was produced, and after twenty-five years of labor he was able (in 1761) to offer an instrument

which he claimed would answer the desired purpose. In this year Harrison made a voyage to Jamaica; the longitude of Port Royal, by his chronometer, differed from that deduced from a transit of Mercury by only one minute of arc. On his return the chronometer was found to be about two minutes slow; for these results Harrison was awarded five thousand pounds sterling. In 1764, Harrison again made a voyage to the West Indies, having, in the meantime, made some improvements in his chronometer; before sailing, he deposited with the Admiralty a statement as to his expectations of the rate of the chronometer at different temperatures, and also of its probable mean rate. On his return the chronometer was found to be less than one minute out on its mean rate, and but fifteen seconds out when account was taken of the temperatures to which it had been subjected. The instrument and the working drawings, with a statement of the principles involved in its construction, being delivered to the Board, a further reward of ten thousand pounds sterling was paid, the remainder being promised when it was found that an instrument constructed by some other person from his drawings should be equally successful. The one so made was used by Cook in his voyage of circumnavigation in 1772–74; and the report of its performance was such as to cause the remainder of the reward to be paid to Harrison; he also received gratuities from the East India Company and others; so that for his efforts of forty years, he received about twenty-five thousand pounds sterling; by no means an inadequate reward, if we consider the immense benefit conferred upon the mariner by his invention. During the last century the watchmaker's art has made great progress and the best chronometers furnished at the present day are far more reliable for the determination of the longitude than any lunar observations can possibly be; and yet it is by no means wise to trust them entirely; the careful navigator finds that here, as in all other parts of his practice, "eternal vigilance is the price of safety."



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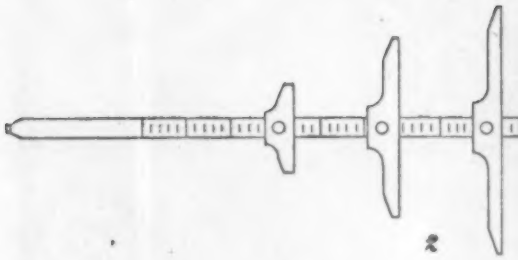

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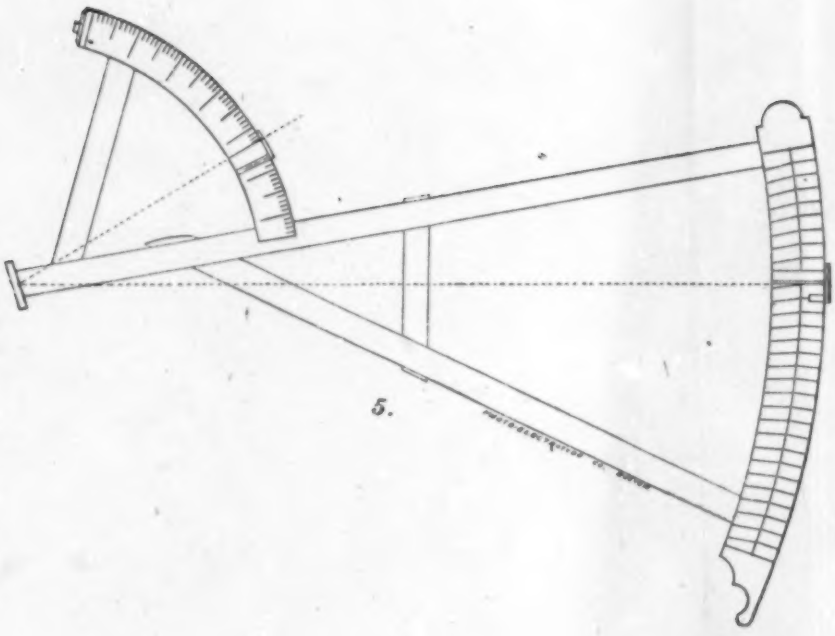

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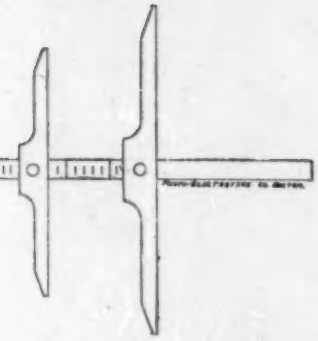

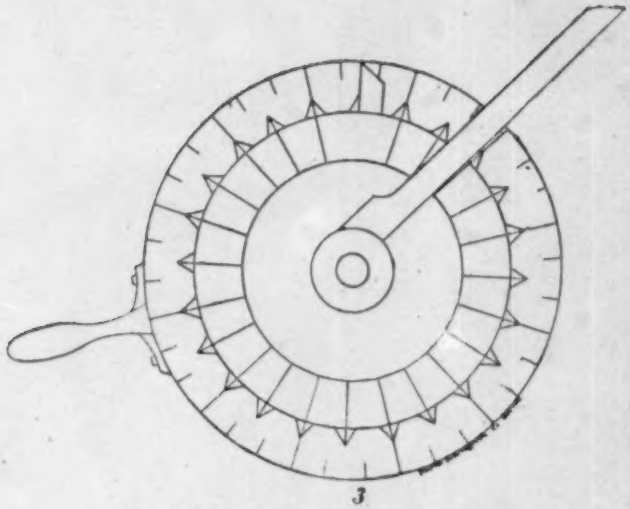

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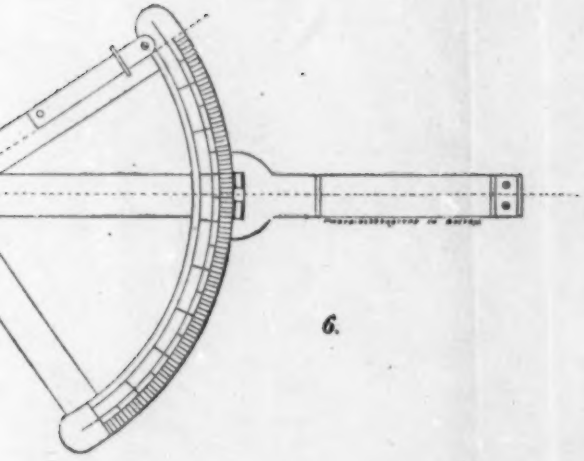

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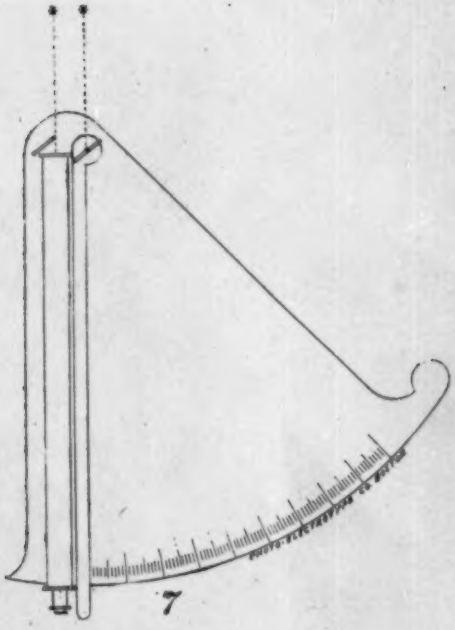

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